



Office of Intellectual Property

(11) (C) 1,331,820  
(21) 586,431  
(22) 1988/12/20  
(45) 1994/08/30  
(52) 400-6498

REPORTS  
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MARKS  
DE COMMERCE  
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DESIGNS  
D'INVENTION  
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DESIGNS  
INDUSTRIELS  
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TÉMOIGNAGES  
DE CAS  
DE DÉPOSÉS

(51) INTL. CL. C08F-212/08; C08F-279/02

(19) (CA) CANADIAN PATENT (12)

(54) Continuous Process Including Recycle Stream Treatment  
for the Production of High Impact Polystyrene

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(30) (US) U.S.A. 137,743 1987/12/24  
(US) U.S.A. 137,889 1987/12/24  
(US) U.S.A. 138,089 1987/12/24

(57) 33 claims

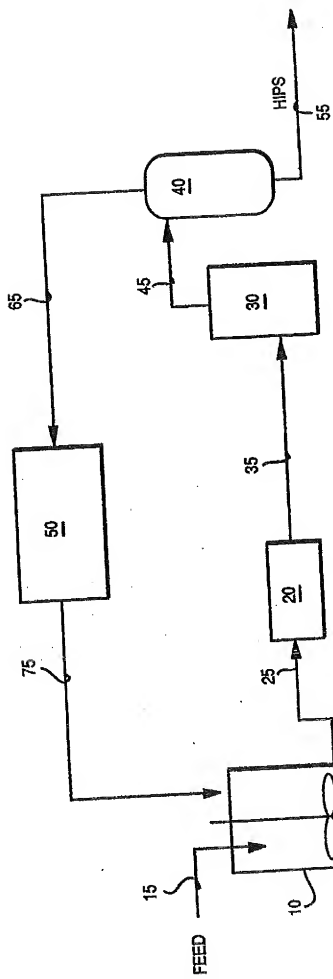


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CONTINUOUS PROCESS INCLUDING RECYCLE  
STREAM TREATMENT FOR THE PRODUCTION  
OF HIGH IMPACT POLYSTYRENE

FIELD OF THE INVENTION

5 The present invention relates to a process for producing high impact polystyrene. More particularly, the invention relates to a continuous flow process for producing polystyrene having discrete particles of rubber included therein.

BACKGROUND OF THE INVENTION

10 It is well known that rubber-reinforced polymers of monovinylidene aromatic compounds, such as styrene, alpha-methylstyrene and ring-substituted styrene, are useful for a variety of purposes. For example, rubber-reinforced styrene polymers having discrete particles of a cross-linked rubber,  
15 e.g., polybutadiene, dispersed throughout the styrene polymer matrix can be used in a variety of diverse applications including refrigerator linings, packaging applications, furniture, household appliances and toys. Such rubber-reinforced polymers are commonly referred to as "high impact  
20 polystyrene" or "HIPS".

One known process for producing HIPS polymers is the batch or suspension process wherein polymerization occurs within a single reaction vessel. An advantage of the batch process is the ease with which HIPS production can be  
25 controlled and monitored due to the use of a single reaction vessel throughout the entire polymerization process. However, the batch process suffers from a number of inherent disadvantages, such as low yields and extended down-time periods, which render it unsuitable for commercial purposes.

30 In order to overcome the commercial difficulties of the batch process, several continuous flow processes for the production of HIPS have been proposed. Such known processes employ a plurality of serially arranged reaction vessels wherein the degree of polymerization increases from one vessel  
35 to the next. See, for example, U.S. Patent 3,658,946 to

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Bronstert et al., U.S. Patent 3,243,481 to Ruffing et al.,  
U.S. Patent 4,451,612 to Wang et al., and U.S. Patent  
4,567,232 to Echte et al.

Several of these continuous process patents generally  
5 suggest that some type of devolatilization zone and recycle  
pathway be used for returning solvents and unreacted monomer  
to one of the polymerization reaction zones. However, the  
recycle stream leaving the devolatilization zone contains a  
substantial amount of impurities, including residual  
10 antioxidants and antioxidant decomposition by-products, and/or  
free radical initiator decomposition by-products, which can  
adversely affect the continuous HIPS production process when  
the impurities are introduced into a polymerization zone. In  
fact, these impurities can destroy the effectiveness of a free  
15 radical initiator and inhibit polymerization for a significant  
period of time, even indefinitely, when the recycle stream is  
fed into the initial polymerization reaction zone. Further,  
such impurities can impart undesirable physical  
characteristics, such as discoloration, to the HIPS polymers.  
20 None of the above patents recognize either the cause or  
the effects of recycle stream impurities. Similarly, none of  
those patents provides any means for overcoming the adverse  
effects of these impurities in the recycle stream upon a  
continuous flow process for producing HIPS polymers.

25 SUMMARY OF THE INVENTION

The present invention overcomes the disadvantages of  
known continuous HIPS production processes. In particular,  
the present invention provides a continuous flow process  
wherein specific types of free radical initiators are used to  
30 optimize polymerization, specific types of antioxidants are  
utilized to prevent undesirable oxidation of the rubber and  
styrene, and specific types of polymerization inhibiting  
impurities are removed from a recycle stream prior to feeding  
or introducing the recycle stream into a polymerization zone.  
35 In a preferred embodiment, the inventive process further  
comprises the step of monitoring the acidity of the recycle

stream. In another preferred embodiment, non-volatile antioxidants are utilized which do not decompose to form by-products which are volatile at the temperatures at which the inventive process operates. In an additional embodiment, free radical initiators are used which decompose only into non-acid by-products.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and further features of the present invention will be better understood when considered in conjunction with the accompanying drawings, wherein like numerals denote corresponding parts, and wherein:

Figure 1 is a schematic representation of reaction vessels and apparatus useful in the process of the present invention.

Figure 2 is a schematic representation of another embodiment of reaction vessels and apparatus useful in the process of the present invention.

Figure 3 is a graph showing the effect of benzoic acid on the polymerization of styrene in the presence of a free radical initiator.

Figure 4 is a thermogravimetric analysis of exemplary antioxidants.

#### DETAILED DESCRIPTION OF THE INVENTION

Referring now to Figures 1 and 2, there is shown a schematic representation of a series of reaction vessels and apparatus useful in the practice of the continuous HIPS production process of the present invention.

Styrene, polybutadiene, a free radical initiator, an antioxidant, and additional components such as solvents and other additives are fed to a polymerization reactor 10 through a feed line or lines generally indicated at 15. The antioxidant may alternatively be introduced at other points in the system. As used herein, the term "styrene" includes a variety of substituted styrenes, e.g., alpha-methyl styrene, ring-substituted styrenes such as p-methylstyrene and p-

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chlorostyrene, as well as unsubstituted styrene. Typically, the mixture in polymerization reactor 10 will comprise about 75 to 99% by weight styrene, about 1 to 15% by weight polybutadiene, about 0.001 to 0.2% by weight free radical initiator, about 0.05 to 0.08% by weight antioxidant, and the remainder, additional components.

Polymerization reactor 10 is preferably a continuously stirred tank reactor which operates at a percent solids level above the inversion point of the polymer system. That is, the polymerization reactor 10 operates at a percent solids level such that the system has a continuous phase of polystyrene a discontinuous phase of dispersed droplets of rubber, or preferably, the droplets are a mixture of polystyrene and rubber. Reactor 10 is preferably maintained at a temperature of 120° to 135°C, and a pressure of about 1/2 atmosphere.

The apparatus used in practicing the present invention may also comprise an additional polymerization reactor 11 which is operated at pre-inversion conditions, i.e., the continuous phase therein is a styrene-rubber solution and the discontinuous phase is polystyrene. This pre-inversion reactor 11 is located directly before the polymerization reactor 10, such that the styrene, polybutadiene, free radical initiator, antioxidant, and other components are fed to the pre-inversion reactor 11 and the mixture exiting the pre-inversion reactor is then fed to polymerization reactor 10. The pre-inversion reactor is preferably a continuously stirred tank reactor. The antioxidant is preferably added to the system after the pre-inversion reactor, for instance in a line or flow reactor as described hereafter.

Output from the polymerization reactor 10 is fed to another polymerization reactor through line 25 and post-inversion stage polymerization occurs in this next polymerization reactor. Preferably, this next polymerization reactor is a linear-flow reactor, such as a plug flow reactor, but may also be a tower-type reactor or other known reactor

design. Fig. 1 shows a single linear-flow reactor 20; Fig. 2 shows two linear-flow reactors 21 and 22; and more linear-flow reactors may be serially connected with increased polymerization occurring in each subsequent reactor. The temperature and pressure of the flow are gradually increased as it passes through the linear-flow reactors. Output from polymerization reactor(s) 20 (21,22) which is preferably at a temperature of about 155° to 165°C and a pressure less than about 40 PSI, is directed to a pre-heater 30 and then to a conventional devolatilizer 40 where the temperature rises to about 235°C at a vacuum of about 10-40mm Hg, through lines 35 and 45 respectively. The resultant HIPS polymer is removed from devolatilizer 40 through line 55 and directed to a conventional pelletizer (not shown) or the like. The HIPS polymer thus produced has a notched Izod value of 1.9 to 3.9 ft/lb, a Gardner falling dart value of 80 to 160 in/lb, and a tensile strength of 2600 to 4500 psi. These HIPS polymers have excellent color and gloss and are suitable for many applications.

Unreacted styrene monomer and other volatile residual components leave devolatilizer 40 through line 65 as a recycle stream. It is preferably returned to the system after condensation in condenser means 66, storage and treatment in tank 67 and treatment in recycle treatment means 50, at a polymerization reactor 10 through line 75, as shown in Fig. 1. As shown in Fig. 2, besides being returned to the system at polymerization reactor 10 through line 77, it may alternatively be returned to the system at pre-inversion reactor 11 or at linear-flow reactor 21 through line 76 or 78, respectively. The recycle stream contains a variety of impurities. The major impurities in the recycle stream can be traced to products of reactions between species necessarily present in the recycle stream, such as styrene monomer and antioxidant, impurities from the rubber, and unwanted species in the system, such as oxygen. Although some of the recycle

stream impurities are innocuous, it has been unexpectedly discovered that certain impurities in the recycle stream adversely affect the polymerization process or the resultant HIPS product when the recycle stream is introduced into the system.

5 In the continuous process of the present invention, polymerization of the styrene monomer is initiated by the decomposition of a free radical initiator. Initiating radicals for the polymerization reaction are generated by the  
10 decomposition of the free radical initiator into one or more primary radicals. The primary radical then reacts with styrene monomer to initiate polymerization.

Typically, the free radical initiator is fed to the first polymerization reactor 10, which is maintained at conditions  
15 under which the free radical initiator decomposes, although it may also be fed to pre-inversion reactor 11 or linear-flow reactor 21. The free radical initiator may alternatively be selected such that it will not decompose in the first  
20 polymerization reactor 10 and instead will decompose under the conditions maintained in a subsequent polymerization reactor. In this case, polymerization of styrene monomer in polymerization reactor 10 could be thermally initiated. Alternatively, a combination of two or more free radical  
25 initiators could be used, such that one free radical initiator decomposes in the polymerization reactor 10 and another free radical initiator decomposes in the linear-flow reactor 20 (21, 22).

Decomposition of the free radical initiator, which initiates polymerization of the styrene monomer, also produces  
30 decomposition by-products which do not participate in the polymerization reaction. In the present continuous flow process, these decomposition by-products of the free radical initiator are removed from the HIPS polymer in the devolatilizer 40 and appear in the recycle stream.

35 After investigating the effects of various recycle stream



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components upon styrene polymerization, it has been discovered that acid decomposition by-products of free radical initiators react with such initiators, thereby inhibiting styrene polymerization. It is believed that these acidic decomposition by-products adversely affect free radical initiator efficiency by inducing decomposition of the free radical initiator and/or trapping free radicals produced by spontaneous, as opposed to induced, decomposition of the free radical initiator. Thus, the acidic decomposition by-products decrease the number of free radicals available to initiate polymerization of the styrene monomer and decrease the efficiency of the free radical initiator.

Benzoic acid is one example of an acid decomposition by-product having such an adverse effect. The recognition that benzoic acid in the recycle stream inhibits styrene polymerization in the presence of a free radical initiator is particularly significant because benzoic acid is a decomposition by-product of t-butyl peroxybenzoate and dibenzoyl peroxide, two of the most commonly used free radical initiators in the continuous process production of HIPS. Benzoic acid is also produced from the air oxidation of benzaldehyde, which in turn is produced from the oxidation of styrene. Other acidic species may be present in the polybutadiene rubber. It is well known that phenolic anti-oxidants, sulfur components and substituted phosphites are added to protect the rubber from oxidation.

Examples of acid-producing free radical initiators and their corresponding acid decomposition by-products are set forth in Table 1. Those examples show that peroxy free radical initiators are a useful class of initiators for such processes, but that acidic decomposition by-products of such peroxy free radical initiators produce undesirable effects which the present invention is intended to alleviate. Applicants' recognition of such acidic by-products as a source of a problem in the manufacture of HIPS products is a

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significant aspect of the present invention.

TABLE 1

	Dilauroyl peroxide	Lauroyl acid
	Diocetyl peroxide	Caprylic acid
5	Didecanoyl peroxide	n-Decanoic acid
	Di-n-propionyl peroxide	Propionic acid
	Bis(3,5,5-trimethyl hexanoyl) peroxide	3,5,5-Trimethyl hexanoic acid
10	Dibenzoyl peroxide	Benzoic acid
	Bis(2,4-dichlorobenzoyl) peroxide	2,4 Dichlorobenzoic acid
	Bis(o-methylbenzoyl) peroxide	o-Methyl benzoic acid
	Acetyl cyclohexane sulphonyl peroxide	Cyclohexane sulphonc acid
15	t-Butylperoxy-pivalate	Pivalic acid
	t-Butyl peroxy-2-ethylhexanoate	2-Ethyl caprioic acid
	t-Butyl peroxy isobutyrate	Isobutyric acid
	t-Butyl peroxybenzoate	Benzoic acid

- 20 All of the above-listed acid decomposition by-products are believed to have a detrimental effect on the efficiency of free radical initiation of styrene polymerization.

Fig. 3 graphically illustrates the unexpectedly detrimental effects of benzoic acid upon styrene polymerization in the presence of the free radical initiator t-butylperoxy-benzoate. This inhibitory effect of benzoic acid is a decomposition by-product of t-butylperoxybenzoate and dibenzoyl peroxide, initiators which have long been widely used in catalyzing styrene polymerization reactions. Table 2 below lists the inhibition time and percent polymerization after specified time intervals at varying ratios of t-butylperoxybenzoate (TBP) to benzoic acid, which is graphically presented in Fig. 3.

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TABLE 2  
POLYMERIZATION OF STYRENE IN PRESENCE OF TBP AND BENZOIC  
ACID AT 120°C UNDER N<sub>2</sub>

5	Ratio of TBP:Acid	% Polymer at (min)							(min) Inhib. Time
		0	10	20	30	40	50	60	
	1:0	0	1.0	3.4	4.7	6.7	8.2	9.9	7.5
	1:1	0	0.85	2.4	3.9	4.9	6.6	7.5	7.0
	1:2	0	0.21	2.0	3.8	5.0	6.4	6.8	13.0
10	1:4	0	0.42	2.2	4.2	4.4	7.5	8.8	11.0

As clearly indicated in Table 2 and Fig. 3, the polymerization inhibition time at TBP:Acid ratios of 1:1 and 1:0 is significantly less than at ratios of 1:2 and 1:4. Initially, the benzoic acid apparently contributes to an inhibition process (see the amount of polymer formed after 10 minutes). After the inhibition or retardation effect is overcome, the polymerization reaction proceeds normally. However, in a stream with continuous recycle, the inhibitory effect would constantly be present as fresh recycle stream is continuously fed to the polymerization reactor.

A reduction in inhibition time has a marked effect upon the overall continuous HIPS production process. A reduction in inhibition time advantageously results in increased free radical initiator efficiency, decreased residence time in the initial polymerization zone and an increased production rate without the necessity of providing additional equipment.

According to the process of the present invention, the adverse effects of acid decomposition by-products of free radical initiators, such as t-butylperoxybenzoate, dibenzoyl-peroxide and the free radical initiators listed in Table 1, are avoided by directing the recycle stream to a recycle treatment vessel 50 interposed between devolatilizer 40 and recycle stream feed line 75. Recycle treatment vessel 50 comprises at least one adsorbent material, such as alumina or clay, which is capable of removing acid components from the recycle stream. Examples of specific adsorbent materials

include alumina, attapulgus clay, carbon, silica gels and Porocel™ (an alumina). The size and shape of the recycle treatment vessel are determined according to standard engineering practices. Preferred is a clay tower, maintained at 80-120°C and 20-25 psi pressure.

While the recycle treatment vessel must be capable of removing substantially all of the acid components from the recycle stream, it is highly desirable that the adsorbent used also be capable of removing other impurities, both identified and unknown, from the recycle stream. The combined effects of all impurities, including acid decomposition by-products, upon styrene polymerization reaction rate and upon the average rubber particle size in the resultant HIPS polymer are significantly detrimental, and increase with an increase in the amount of impurities.

According to another preferred embodiment of the present invention, the continuous process for the production of HIPS further includes the step of monitoring the acidity and/or purity of the treated recycle stream prior to feeding the treated recycle stream back into the polymerization stream. The acidity of the treated recycle stream should be monitored to ensure that the recycle treatment vessel is effectively eliminating acid components from the recycle stream. The acidity of the treated recycle stream is considered adequately controlled when the treated recycle stream contains less than 0.08% acid components. Preferably, the treated recycle stream contains less than 0.03% acid components, and most preferably less than 0.01%. The recycle treatment vessel should be readjusted after a period of use, either regularly or based on results of monitoring recycle stream purity. For instance, clay adsorbent in a clay tower should be replaced when recycle stream purity diminishes.

Several means for monitoring the acidity and/or purity of the treated recycle stream can be used in accordance with the presently claimed invention. Three preferred monitoring

procedures are: a water wash pH test, a recycle purity test and a total acid number test.

The water wash pH test comprises the steps of pouring equal amounts of distilled or dionized water and a sample of the treated recycle into a separatory funnel; shaking the separatory funnel for at least 15 seconds; allowing the phases in the separatory funnel to separate for about five minutes, draining the lower water layer from the separatory funnel into a beaker; and then determining the pH of the water using a conventional pH meter. If the pH of the water is less than 6.5, the treated recycle stream has an unacceptably high acid content and the adsorbent in the recycle stream vessel should be replaced to ensure that the treated recycle stream does not have any adverse effects upon the polymerization of styrene in the polymerization system. Preferably, the pH of the water should be 6.8 to 7.0.

The recycle purity test detects the presence of phenolic compounds which react with peroxides to give colored compounds that are potent inhibitors. It is conducted as follows. A clay treated styrene is prepared by filling a separatory funnel with clay, filling the funnel with styrene, allowing the styrene and clay to stand for about five minutes, draining the separatory funnel slowly, and filtering the styrene to remove clay fines. To conduct the recycle purity test, a blank containing about 40 ml of clay treated styrene and four drops of t-butylperoxybenzoate and a sample containing 40 ml of the treated recycle stream and four drops of t-butylperoxybenzoate are prepared. The blank and the sample are heated in an oven at a temperature of 130-135°C for about ten minutes. The blank and the sample are visually inspected to determine the presence or absence of a yellow color. Next, the percent transmittance of the sample is determined using a spectrophotometer. The wave length of the spectrophotometer is set to 400 nm and 0% transmittance without a cell in the instrument. The blank is inserted into the spectrophotometer

and the transmittance is set to 100%. Next, the sample is inserted into the spectrophotometer and the percent transmittance of the sample is determined. A clean treated recycle stream will be water-white, i.e., no evidence of yellow color, and the percent transmittance will be greater than 95%.

The most preferred method for monitoring the acid content of the treated recycle stream is the total acid number test. The total acid number test is adapted from ASTM D 974-80 and comprises the following steps. A titration solvent is prepared by adding 500 ml of toluene and 5 ml deionized water to 495 ml of anhydrous isopropyl alcohol. A p-naphtholbenzein indicator solution is prepared by dissolving 1.0 gram of p-naphtholbenzein in 100 ml of the titration solvent. To perform the sample titration, about 20 grams of the treated recycle stream, 100 ml of the titration solvent and 10 drops of the indicator solution are introduced as a sample solution into a suitable container such as a flask. This sample solution is swirled, without stoppering, until the sample is entirely dissolved by the solvent. The sample solution is then titrated immediately at a temperature below 30°C by adding 0.01N alcoholic KOH solution in increments and swirling to disperse the KOH as necessary. The titration is continued until the orange color of the sample solution changes to a green or green-brown color. The end point of the titration is considered definite if the color change persists for 15 seconds. The quantity of 0.01N alcohol KOH required to reach the end point is recorded. A blank titration on 100 ml of the titration solvent and 10 drops of the indicator solution is performed by incrementally adding 0.01 N alcoholic KOH solution until the orange to green or green-brown color change occurs, indicating the end point. The quantity of 0.01 N alcoholic KOH required to reach the end point of the blank titration is recorded. The total acid number (T), expressed as mg of KOH/g, of the treated recycle stream, is calculated

by the formula:  $T = ((A-B)N \times 56.1)/W$ , wherein a is the number of ml of KOH solution required for titration of the sample solution, B is the number of ml of KOH solution required for titration of the blank, N is the normality of the KOH solution, and W is the weight of the sample used. The treated recycle stream is considered to be clean or to have a sufficiently low acid content if the total acid number is 0.08 or lower. Preferably, the total acid number should be less than 0.03, more preferably less than 0.01.

According to a further aspect of the process of the present invention, the adverse effects of acid decomposition by-products of free radical initiators, such as t-butylperoxybenzoate, dibenzoyl-peroxide and the free radical initiators listed in Table 1, are avoided by careful selection of the free radical initiator. The choice of free radical initiator is an important aspect of the present invention. Suitable free radical initiators are those which do not form acid by-products upon decomposition. The useful free radical initiators decompose to form innocuous decomposition by-products which do not react with the free radical initiator or other components of the polymerization system, such as anti-oxidant or styrene monomer, to inhibit the styrene polymerization reaction. Since the decomposition by-products are recycled to polymerization zones in the system, the decomposition by-products must not react with the free radical initiator so as to deactivate the free radical initiator and must not function as chain terminators for the styrene polymerization reaction.

Examples of free radical initiators useful in the present process include azo-compounds such as 2,2'-azo-bis-iso-butyronitrile and 2,2'-azo-bis(2,4-dimethyl valeronitrile); and peroxy compounds such as peroxydicarbonates such as di(n-propyl)peroxydicarbonate; di(sec-butyl)peroxydicarbonate; di(2-ethylhexyl)peroxydicarbonate; dialkyl peroxides such as dicumyl peroxide; 2,5-dimethyl-2,5-di(t-butylperoxy)hexane; t-

butyl cumyl peroxide; -bis(t-butyl peroxy)diisopropylbenzene; di-t-butyl peroxide; 2,5-dimethyl-2,5-di(t-butylperoxy)hexyne-3; hydroperoxides such as 2,5-dihydroperoxy-2,5-dimethylhexane; cumene hydroperoxide; t-butyl hydroperoxide; t-amyl hydroperoxide; peroxyketals such as n-butyl-4,4-bis(t-butylperoxy)valerate; 1,1-di(t-butylperoxy)cyclohexane; 1,1-di(t-butylperoxy)cyclohexane; 2,2-di(t-butylperoxy)butane; ethyl-3,3-di(t-butylperoxy)butyrate; t-butyl peroctoate and 1,1-di(t-butylperoxy)cyclohexane blend; 2,2-di(t-amylperoxy)propane; and ethyl-3,3-di(t-amylperoxy)butyrate. Of these free radical initiators, the peroxy ketal compounds are preferred, particularly ethyl-3,3-di(t-butylperoxy)butyrate and 1,1-di(t-butylperoxy)cyclohexane.

Of course, the specific free radical initiator or combination of initiators will be determined within the bounds of the invention by the desired process parameters such as rate of polymerization reaction, degree of polymerization, reactor temperatures, degree of grafting, and the like. The amount of free radical initiator to be used is from 10 to 2000 ppm, preferably 50 to 600 ppm, based on the total content of the polymer system in the first polymerization reactor.

It has also been discovered that volatile antioxidants and antioxidant decomposition by-products react with free radical polymerization initiators, thereby inhibiting styrene polymerization. It is believed that these volatile antioxidants and decomposition by-products adversely affect free radical initiator efficiency by trapping free radicals produced by decomposition of the free radical initiator.

Butylated hydroxy toluene (BHT) is one example of a volatile antioxidant having such an adverse effect. The recognition that BHT in the recycle stream inhibits styrene polymerization in the presence of a free radical initiator is particularly significant because BHT is one of the most commonly used antioxidants in the continuous process



production of HIPS.

According to the process of the present invention, the adverse effects of volatile antioxidants, such as BHT, are avoided by careful selection of the antioxidant. Suitable  
5 antioxidants are those which are non-volatile at the temperatures and pressures, including the devolatilizer temperature, employed in the continuous process for producing HIPS. The useful antioxidants and their decomposition by-products are non-volatile and thus are removed from the system  
10 with the HIPS product. The non-volatile antioxidants and by-products do not become part of the recycle stream and the undesirable build-up of antioxidant in the polymer system is avoided. Since the antioxidant and by-products are not returned to the polymerization reactors in the recycle stream,  
15 residual antioxidant and by-products are not available to react with and deactivate the free radical initiator and do not function as chain terminators for the styrene polymerization reaction.

The specific non-volatile antioxidant will be determined  
20 by the desired process parameters such as rate of polymerization reaction, degree of polymerization, reactor temperatures, degree of grafting, and the like. The amount of non-volatile antioxidant to be used is from 0.05 to 0.15% by weight based on the total content of the polymer system. The  
25 antioxidant must be non-volatile at temperatures of at least about 235°C under vacuum of 10 to 40 mm Hg.

To those skilled in the art, it will be apparent that the volatility of a chemical compound is a measure of its ability to sublime or vaporize at given temperatures and pressures.  
30 In general, highly polar, high molecular compounds will volatilize at higher temperatures. For instance, BHT, with a molecular weight of 220 and a melting point of about 69-70° will have a vapor pressure of about 60 mm of Hg at 300°C and about 560 mm of Hg at 350°C, whereas octadecyl-3,5-di-tert-  
35 butyl-4-hydroxy-hydrocinnamate, with a molecular weight of

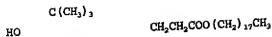
about 531 and a melting point of about 49-54°C, will have a vapor pressure of about 4 mm of Hg at 250°C and a vapor pressure of 30 mm of Hg at 300°C.

It is known to those skilled in the art to determine weight loss of an antioxidant to determine the amount of antioxidant which will remain in the final product as a function of temperature and pressure, as shown in Fig. 3, by measuring the percentage of a sample remaining as temperature is increased at a heating rate of 10°C per minute in N<sub>2</sub> at atmospheric pressure. In Fig. 3, curve 80 represents BHT, curve 81 represents 2,2'-methylene-bis(4-methyl-6-tert-butylphenol) (MBMBP), curve 82 represents octadecyl-1,5-di-tert-butyl-4-hydroxy-hydrocinnamate, curve 83 represents 2,4-bis-(n-octylthio)-6-(4-hydroxy-3,5-di-tert-butylanilino)-1,3,5-triazine and curve 84 represents tetra-kis(methylene-3-(3,5-di-tert-hydroxyphenylpropionate)-methane).

In practicing the present invention, volatility can be measured in terms of weight loss in the same manner. Preferred antioxidants will lose less than 1.0%, preferably less than 0.1%, of their weight at 250°C in N<sub>2</sub> at 1 atmosphere pressure. Selection of antioxidants for given applications depends on the process temperatures and pressures, as well as on other factors such as color, solubility, cost and availability. Those of skill in the art have available numerous compounds that can serve as antioxidants; see, for example, Goodyear Chemicals, Index of Commercial Antioxidants and Antiozonants, Third Edition, 1982. Those of ordinary skill in the art would be capable of selecting antioxidants on the basis of the above disclosure from among known antioxidants based upon the above-discussed volatility parameters without undue experimentation.

Examples of non-volatile antioxidants useful in the present process include octadecyl-3,5-di-tert-butyl-4-hydroxy-hydrocinnamate;

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2,4-bis(n-octylthio)-6-(4-hydroxy-3,5-di-tert-butylanilino)-  
1,3,5-triazine:

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and triethylene glycol-bis(3-(3'-tert-butyl-4'-hydroxy-5'-methylphenyl)propionate).

Although the invention has been described with reference to particular embodiments thereof, it will be apparent to those skilled in the art that various changes and modifications can be made without departing from the spirit of the invention or from the scope of the appended claims.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A continuous process for producing high impact polystyrene, comprising:
  - polymerizing a mixture comprising at least one vinylaromatic monomer, a rubber and a non-volatile antioxidant in at least one polymerization reactor said polymerization being initiated by a free radical initiator;
  - feeding said mixture to a pre-heater to heat said mixture and produce a heated mixture;
  - feeding said heated mixture to a devolatilizer to remove volatile components from said heated mixture, thereby producing a high impact polystyrene; and
  - feeding said volatile components as a recycle stream to said at least one polymerization reactor;wherein said non-volatile antioxidant is selected to exhibit a weight loss at 250°C under N<sub>2</sub> at 1 atmosphere pressure of less than 1.0%.
2. A process of claim 1, wherein said weight loss is less than 0.1%.
3. A process of claim 1, further comprising the steps of:
  - polymerizing said mixture of vinylaromatic monomer and rubber in a first polymerization reactor to a degree above an inversion point of said mixture; and
  - feeding said mixture into at least a second polymerization reactor to further polymerize said mixture prior to feeding said mixture to said pre-heater.
4. A process of claim 3, wherein said first polymerization reactor is a continuously stirred tank reactor.
5. A process of claim 4, wherein said second polymerization reactor is a linear-flow reactor.
6. A process of claim 5, further comprising the step of feeding said mixture to at least one additional linear-flow reactor prior to heating said mixture in said pre-heater.
7. A process of claim 1, wherein said non-volatile antioxidant is at

least one member selected from the group consisting of 2,4-bis(n-octylthio)-6-(4-hydroxy-3,5-di-tert-butylanilino)-1,3,5-triazine and triethylene glycol-bis(3-(3'-tert-butyl-4'-hydroxy-5'-methylphenyl)propionate).

8. A process of claim 1, wherein said non-volatile antioxidant comprises octadecyl-3,5-di-tert-butyl-4-hydroxyhydro-cinnamate.

9. A continuous process for producing high impact polystyrene, comprising:

feeding at least one vinylaromatic monomer, a rubber and a non-volatile antioxidant to a first continuously stirred tank reactor to form a first mixture therein;

polymerizing said first mixture in said first continuously stirred tank reactor to a point below an inversion point of the first mixture said polymerization being initiated by a free radical initiator;

feeding said first mixture to a second continuously stirred tank reactor;

polymerizing said first mixture in said second continuously stirred tank reactor to a point above an inversion point of said first mixture;

feeding said first mixture to a series of at least two linear-flow reactors to further polymerize said first mixture and produce a second mixture, wherein the degree of polymerization of said first mixture increases in each of said linear-flow reactors;

feeding said second mixture to a pre-heater to heat said second mixture and produce a heated mixture;

feeding said heated mixture to a devolatilizer to remove volatile components from said heated mixture, thereby producing a high impact polystyrene; and

feeding said volatile components as a recycle stream to at least one of said reactors;

wherein said non-volatile antioxidant is selected to exhibit a weight loss at 250°C under N<sub>2</sub> at 1 atmosphere pressure of less than 0.1%.

10. A continuous process for producing high impact polystyrene, comprising:

polymerizing a mixture of at least one vinyl-aromatic monomer and a rubber in a polymerization reactor, said polymerization being initiated by a free radical initiator which decomposes to form at least one initiating radical and substantially only non-acidic decomposition by-products;

feeding said mixture to a pre-heater to heat said mixture and produce a heated mixture;

feeding said heated mixture to a devolatilizer to remove volatile components including said non-acidic decomposition by-products of the free radical initiator from said heated mixture, thereby producing a high impact polystyrene; and feeding said volatile components as a recycle stream to said polymerization reactor;

wherein introduction of the non-acidic decomposition by-products in the recycle stream into the polymerization reactor does not inhibit polymerization of the vinylaromatic monomer; and

wherein the non-acidic decomposition by-products do not react with the free radical initiator to inhibit polymerization of the vinylaromatic monomer.

11. A process of claim 10 further comprising the steps of:

polymerizing said mixture of the vinylaromatic monomer and the rubber in a first polymerization reactor to a degree above an inversion point of said mixture;

feeding said mixture into at least a second polymerization reactor to further polymerize said mixture prior to feeding said mixture to said pre-heater.

12. A process of claim 11, wherein said first polymerization reactor is a continuously stirred tank reactor.

13. A process of claim 12, wherein said second polymerization reactor is a linear-flow reactor.

14. A process of claim 13, further comprising the step of feeding said mixture to at least one additional linear-flow reactor prior to heating said mixture in said pre-heater.

15. A process of claim 10, wherein said free radical initiator is added to said mixture in an amount of 10-2000 ppm based on a total content of said mixture.

16. A process of claim 15, wherein said amount is 50-600ppm based on a total content of said mixture.

17. A process of claim 10, wherein said free radical initiator is an azo compound.

18. A process of claim 17, wherein said azo compound is at least one member selected from the group consisting of 2,2'-azo-bis-isobutyronitrile and 2,2'-azo-bis-(2,4-dimethyl valero-nitrile).

19. A process of claim 10, wherein said free radical initiator is a peroxy compound.

20. A process of claim 19, wherein said peroxy compound is at least one member selected from the group consisting of peroxydicarbonates, dialkyl peroxides, hydroperoxides and peroxyketals.

21. A process of claim 10, wherein said free radical initiator is at least one member selected from the group consisting of ethyl-3,3-di(t-butylperoxy)butyrate and 1,1-di(t-butylperoxy)cyclohexane.

22. A continuous process for producing high impact polystyrene comprising:

feeding at least one vinylaromatic monomer, a rubber and a free radical initiator to a first continuously stirred tank reactor to form a first mixture therein;

maintaining said first continuously stirred tank reactor at a temperature at which said free radical initiator decomposes, said free radical initiator decomposing to form at least one initiating radical and non-acidic decomposition by-products;

polymerizing said first mixture in said first continuously stirred tank reactor to a point below an inversion point of the first mixture, said polymerization being initiated by a reaction of said initiating radical with said vinyl aromatic monomer;

feeding said first mixture to a second continuously stirred tank reactor;

polymerizing said first mixture in said second continuously stirred tank reactor to a point above the inversion point of the first mixture to produce a second



mixture;

feeding said second mixture to a series of at least two linear-flow reactors to further polymerize said second mixture and produce a third mixture, wherein the degree of polymerization of said second mixture increases in each of said linear-flow reactors;

feeding said third mixture to a pre-heater to heat said third mixture and produce a heated mixture;

feeding said heated mixture to a devolatilizer to remove volatile components including said non-acidic decomposition by-products of the free radical initiator from said heated mixture, thereby producing a high impact polystyrene; and

feeding said volatile components as a recycle stream to said first continuously stirred tank reactor;

wherein introduction of said non-acidic decomposition by-products in the recycle stream into said first continuously stirred tank reactor does not inhibit polymerization of said vinyl-aromatic monomer; and

wherein a reaction between said non-acidic decomposition by-products and said free radical initiator in said first continuously stirred tank reactor does not inhibit polymerization of said vinylaromatic monomer.

23. A continuous process for producing high impact polystyrene comprising:

polymerizing a mixture of at least one vinylaromatic monomer and a rubber in the presence of a free radical initiator in at least one polymerization reactor;

feeding said mixture to a pre-heater to heat said mixture, thereby producing a heated mixture;

feeding said heated mixture to a devolatilizer to eliminate volatile components from said heated mixture, thereby producing a high impact polystyrene polymer;

feeding said volatile components as a recycle stream to a recycle treatment vessel

removing initiator inhibiting impurities from said recycle stream in said recycle treatment vessel to produce a

treated recycle stream containing less than 0.08% by weight of acid component by-products of said free radical initiator; and feeding said treated recycle stream to said polymerization reactor.

5 24. A process of claim 23, wherein said treated recycle stream contains less than 40 total impurities.

25. A process of claim 23, further comprising monitoring an acid content of said treated recycle stream.

10 26. A process of claim 25, wherein the acid content of the treated recycle stream is monitored by an acid number test.

27. A process of claim 26, wherein said recycle stream is maintained with an acid number less than about 0.08.

15 28. A process of claim 26, wherein said recycle stream is maintained with an acid number less than about 0.03.

29. A process of claim 26, wherein said recycle stream is maintained with an acid number less than about 0.01.

30. A process of claim 23, wherein said recycle stream contains less than 0.03% of said acid component by-products.

20 31. A process of claim 23, wherein said recycle stream contains less than 0.01% of said acid component by-products.

32. A continuous process for producing high impact polystyrene comprising:

25 feeding at least one vinylaromatic monomer, a rubber and a free radical initiator to a first continuously stirred tank reactor to form a first mixture therein;

polymerizing said first mixture in said first continuously stirred tank reactor to a point below an inversion point of the first mixture;

30 feeding said first mixture to a second continuously stirred tank reactor;

polymerizing said first mixture in said second continuously stirred tank reactor to a point above the inversion point of the first mixture to produce a second mixture;

35

feeding said second mixture to at least one linear-flow reactor to further polymerize said second mixture and produce a third mixture, wherein a degree of polymerization of said second mixture increases in each said linear-flow reactor;

5 feeding said third mixture to a pre-heater to heat said third mixture and produce a heated mixture;

feeding said heated mixture to a devolatilizer to remove volatile components from said heated mixture, thereby producing a high impact polystyrene polymer;

10 feeding said volatile components as a recycle stream to a recycle treatment vessel;

removing initiator inhibiting impurities from said recycle stream in said recycle treatment vessel to produce a treated recycle stream containing less than 0.08% by weight acid components; and

15 feeding said treated recycle stream to at least one of said reactors.

33. A process of claim 32, wherein said at least one linear-flow reactor comprises a series of at least two linear-flow reactors.



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ABSTRACT OF THE DISCLOSURE

A continuous flow process for the production of high impact polystyrene utilizing a recycle stream of volatile materials and utilizing a non-volatile antioxidant; wherein specific types of polymerization inhibiting impurities are removed from a recycle stream prior to feeding or introducing the recycle stream into a styrene polymerization zone. Preferably, the process further comprises the step of monitoring the acidity of the recycle stream and using a free radical initiator which decomposes to form only non-acid by-products.

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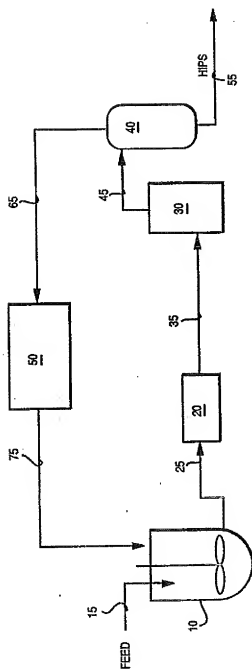


FIG. 1

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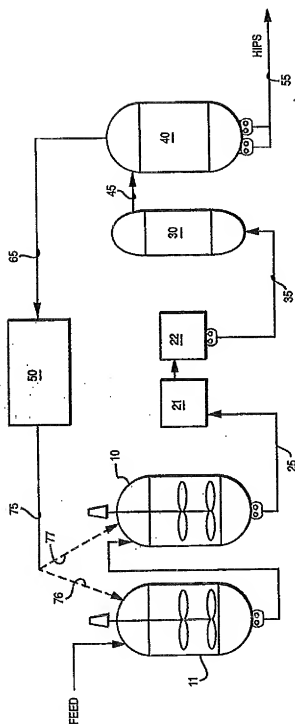


FIG. 2

A

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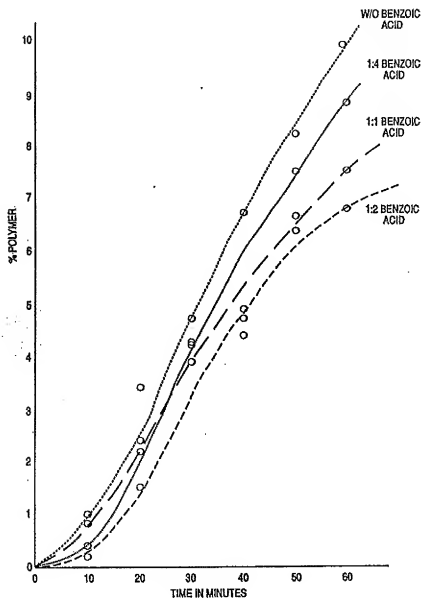
POLYMERIZATION OF STYRENE IN PRESENCE OF TBP AND BENZOIC ACID AT 120°C UNDER N<sub>2</sub>

FIG. 3

A

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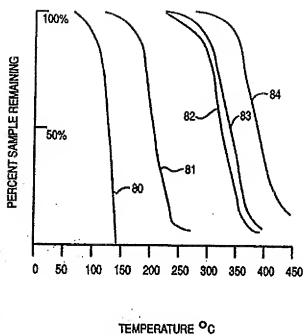


FIG. 4

A

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